

The Radiative Leptonic $B_c \rightarrow \tau \bar{\nu}_\tau \gamma$ Decay in Two Higgs Doublet Model

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Abstract

The radiative leptonic $B_c \rightarrow \tau \bar{\nu}_\tau \gamma$ decay is analysed in context of 2HDM. It is shown that with large values of $\tan\beta$, the contributions of Model II to the decay rate exceeds considerably the Standard Model ones, while the contributions of Model I overlap with the Standard Model predictions.

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1 Introduction

The observation of the B_c -meson by the CDF collaboration in the channel $B_c \rightarrow J/\psi \ell \nu$, with ground state mass $B_c = 6.4 \pm 0.39 \pm 0.13$ GeV, and lifetime $\tau(B_c) = 0.46^{+0.18}_{-0.16} \pm 0.03$ ps [1], has stimulated up the investigation of the properties of B_c -mesons theoretically, and experimentally on a new footing. The particular interest of this observation is related to the fact that, the meson ground-state with $\bar{b}c(b\bar{c})$ can decay only weakly, thus providing the rather unique opportunity of investigating weak decays in a heavy quarkonium system. Moreover, studying this meson could offer an unique probe to check the perturbative QCD predictions more precisely, and one can get essential new information about the confinement scale inside hadrons. The theoretical study of the pure-leptonic decays of B_c -meson, such as $B_c \rightarrow \ell \bar{\nu}_\ell$ ($\ell = e, \mu, \tau$) can be used to determine the leptonic decay constant f_{B_c} [2], as well as the fundamental parameters in the Standard Model (SM), such as the Cabibbo- Kobayashi- Maskawa (CKM) matrix elements which are poorly known at present. Nevertheless, the well-known "helicity suppression" effect make an experimental difficulty in the measurement of purely leptonic decays of B_c . Although, the $B_c \rightarrow \tau \bar{\nu}_\tau$ channel is free of the helicity suppression, the observation of this decay is experimentally difficult due to the efficiency problem for detecting the τ lepton.

Recently, the radiative leptonic $B_c \rightarrow \ell \bar{\nu}_\ell \gamma$ decays ($\ell = e, \mu, \tau$), received considerable attention as a testing ground of SM and "new physics", where no helicity suppression exists any more [3-5].

Among various radiative leptonic decays, the $B_c \rightarrow \tau \bar{\nu}_\tau \gamma$ decay provokes special interest, since the SM predictions has been exploited to establish a bound on the branching ratio of the above mentioned decay of order $\approx 10^{-5}$ [5,6], and therefore can be potentially measurable in the up coming LHC B-factories, where the number of B_c -mesons that will be produced are estimated to be $\approx 2.0 \times 10^{12}$ [7,8]. This will provide an alternative way to determine the decay constant f_{B_c} and the CKM matrix elements. The decay $B_c \rightarrow \tau \bar{\nu}_\tau \gamma$ receive two types of contributions: internal bremsstrahlung (IB), and structure-dependent (SD) parts. The IB contributions are still helicity suppressed, while the SD ones contain the

electromagnetic coupling constant α but they are free of helicity suppression. Therefore, the radiative decay rates of $B_c \rightarrow \ell \bar{\nu}_\ell \gamma$ could have an enhancement with respect to the purely leptonic modes of $B_c \rightarrow \ell \bar{\nu}_\ell$ due to the SD contributions, thus it enable to establish "new physics" beyond the standard model.

In this work, we will study the radiative leptonic $B_c \rightarrow \tau \bar{\nu}_\tau \gamma$ decay in the framework of the two-Higgs doublet model (2HDM) [9-11] at large $\tan\beta$. The so-called Model I and Model II are considered, which are differ only in the couplings of the charged Higgs bosons to fermions. Subsequently, this paper is organized as follows: in section 2, the theoretical formalism relevance for the $B_c \rightarrow \tau \bar{\nu}_\tau \gamma$ decay in 2HDM is presented. Section 3, is devoted to the numerical analysis and the discussion of the results.

2 Formalism for the $B_c \rightarrow \tau \bar{\nu}_\tau \gamma$ decay

In the Standard Model (SM), the decay $B_c \rightarrow \tau \bar{\nu}_\tau \gamma$ can be studied to a very good approximation in terms of four-fermion interactions. The effective Hamiltonian relevant to the process $B_c \rightarrow \tau \bar{\nu}_\tau$ is:

$$H_{eff} = \frac{G_F}{\sqrt{2}} a_1 V_{cb} \bar{c} \gamma_\mu (1 - \gamma_5) b \bar{\tau} \gamma_\mu (1 - \gamma_5) \nu_\tau, \quad (1)$$

where G_F is the Fermi constant, V_{cb} is the CKM mixing element, a_1 is a QCD corrected factor, which is equal $a_1 \simeq 1.13$. However, in the next discussion we will put $a_1 \simeq 1$

The emission of a real photon in leptonic decays of heavy mesons $B_c \rightarrow \tau \bar{\nu}_\tau \gamma$ can proceed via the two mechanisms mentioned in Sec. I. For the IB amplitude, the charged B_c -meson emits leptons via the axial-vector current, and the photon is radiated from the external charged particles. On the other hand the SD amplitude is governed by the vector and axial vector form factors, in which the photon is emitted from intermediate states. Gauge invariance leaves only two form factors $f_{1,2}(p^2)$ undetermined in the SD part. The possible diagrams for this two mechanisms are shown in Fig. 1. Following this framework, the general form of the gauge invariant amplitude corresponding to Fig. 1 can be written as [6]:

$$M(B_c \rightarrow \tau \bar{\nu}_\tau \gamma) = M_1 + M_2, \quad (2)$$

where M_1 and M_2 represent the contributions of "inner bremsstrahlung" (IB), and "structure-dependent" (SD) parts, given by:

$$M_1 = ie \frac{G_F}{\sqrt{2}} V_{cb} f_{B_c} m_\tau \varepsilon_\alpha \bar{u}(p_1) \left\{ \frac{\gamma_\alpha \not{q} + 2p_{1\alpha}}{2p_1 \cdot q} - \frac{p_\alpha}{p \cdot q} \right\} (1 - \gamma_5) v(p_2) , \quad (3)$$

$$M_2 = ie \frac{G_F}{\sqrt{2}} V_{cb} \varepsilon_\alpha \left\{ \frac{-i f_1(p^2)}{m_{B_c}^2} \epsilon_{\alpha\beta\rho\gamma} p_\rho q_\gamma + \frac{f_2(p^2)}{m_{B_c}^2} [p_\alpha q_\beta - g_{\alpha\beta} p \cdot q] \right\} \bar{u}(p_1) \gamma_\beta (1 - \gamma_5) v(p_2) , \quad (4)$$

where ε_α is the photon polarization vector, p_1 , p_2 , and q are the four momenta of τ , ν_τ , and γ , respectively. f_{B_c} is the B_c - meson leptonic decay constant, $f_{1,2}(p^2)$ corresponding to parity conserving and a parity violating formfactors, $p = P_{B_c} = p_1 + p_2$ is the momentum transfer to lepton pair. The necessary matrix elements related to the f_{B_c} , and to the hadron transition form factors $f_{1,2}(p^2)$ are defined as follows [4]:

$$\langle 0 | \bar{c} \gamma_\mu \gamma_5 b | B_c \rangle = -i f_{B_c} P_{B\mu} , \quad (5)$$

$$\langle \gamma(q) | \bar{c} \gamma_\alpha b | B_c(p+q) \rangle = e \frac{f_1(p^2)}{m_{B_c}^2} \epsilon_{\alpha\beta\rho\gamma} \varepsilon^\beta p^\rho q^\gamma , \quad (6)$$

$$\langle \gamma(q) | \bar{c} \gamma_\alpha \gamma_5 b | B_c(p+q) \rangle = -ie \frac{f_2(p^2)}{m_{B_c}^2} \varepsilon_\alpha [g_{\alpha\beta} (p \cdot q) - p_\alpha q_\beta] . \quad (7)$$

We want now to consider the $B_c \rightarrow \tau \bar{\nu}_\tau \gamma$ decay in the context of a 2HDM with no flavor changing neutral currents (FCNC) allowed at the tree level, i.e. Model I and Model II. The interaction lagrangian of fermions with the charged Higgs fields in both models is given by [12]:

$$L = \frac{g_W}{2\sqrt{2}M_W} \left\{ V_{ij} m_{u_i} X \bar{u}_i (1 - \gamma_5) d_j + V_{ij} m_{d_j} Y \bar{u}_i (1 + \gamma_5) d_j + m_\ell Z \bar{\nu} (1 + \gamma_5) \ell \right\} H^\pm + h.c. , \quad (8)$$

where g_W is the weak coupling constant, M_W is the W - boson mass, H^\pm is the charged physical field, and V_{ij} is the relevant elements of CKM matrix. In model I, $X = \cot\beta$, $Y = Z = -\cot\beta$ and in model II, $X = \cot\beta$, and $Y = Z = \tan\beta$.

The decay $B_c \rightarrow \tau \bar{\nu}_\tau \gamma$ in 2HDM proceeds through the same Feynman diagrams (which are displayed in Fig. 1) that mediate the process in SM, except the W -boson is replaced by the charged scalar Higgs boson H^\pm , i.e. ($W \rightarrow H^\pm$).

Fig. 1

The matrix element corresponding to the diagram ($W \rightarrow H^\pm$) where the photon is radiated from τ lepton, (see fig.1) is:

$$M_1^{2HDM} = i e \frac{G_F}{\sqrt{2}} V_{cb} f_{B_c} \varepsilon_\alpha \frac{m_\tau m_{B_c}^2}{M_H^2 (m_b + m_c)} (m_b Z Y - m_c Z X) \times \\ \bar{u}(p_1) \left\{ \frac{2p_{1\alpha} + \gamma_\alpha \not{q}}{2p_1 q} \right\} (1 - \gamma_5) v(p_2) , \quad (9)$$

where f_{B_c} is the leptonic decay constant of B_c meson, defined as:

$$\langle 0 | \bar{c} \gamma_5 b | B_c(p+q) \rangle = -i f_{B_c} \frac{m_{B_c}^2}{(m_b + m_c)} . \quad (10)$$

While the contribution of the structure dependent part to the $B_c \rightarrow \tau \bar{\nu}_\tau \gamma$ decay, i.e., when photon is radiated from initial quark lines, due to the charged Higgs exchange can be

obtained by considering the following correlation function:

$$\begin{aligned}
M_\alpha^{SD} = & -ie \frac{G_F}{\sqrt{2}} V_{cb} \varepsilon_\alpha Z \frac{m_\tau}{M_H^2} \int d^4x e^{iqx} \times \\
& < 0 | T \left\{ \left[\bar{c}(0) (m_b Y (1 + \gamma_5) + m_c X (1 - \gamma_5)) b(0) \right] J_\alpha^{el}(x) \right\} | B_c > \times \\
& \bar{u}(p_1) \gamma_\beta (1 - \gamma_5) v(p_2),
\end{aligned} \tag{11}$$

where $J_\alpha^{el}(x)$ is the electromagnetic current for b or c quarks. The hadronic matrix elements involving the scalar and pseudoscalar currents in Eq.(11) are parameterized such that:

$$\int d^4x e^{iqx} < 0 | T(\bar{c}(0) \gamma_5 b(0) J_\alpha^{el}(x)) | B_c(p+q) > = f_{B_c} \frac{m_{B_c}^2}{(m_b + m_c)} \frac{p_\alpha}{p \cdot q}, \tag{12}$$

$$\int d^4x e^{iqx} < 0 | T(\bar{c}(0) b(0) J_\alpha^{el}(x)) | B_c(p+q) > = 0. \tag{13}$$

The parameterization of the hadronic matrix elements given in Eqs. (12,13) are particularly well suited for our purposes since in the 2HDM, the vertex $b(c) \sim (1 - \gamma_5)$ or $b(c) \sim (1 + \gamma_5)$, hence, the vector part of this correlator is zero, and the active part of this correlator is the axial-part given by:

$$\begin{aligned}
M_\alpha^{A(SD)} = & -ie \frac{G_F}{\sqrt{2}} V_{cb} f_{B_c} \varepsilon_\alpha \frac{m_\tau m_{B_c}^2}{M_H^2} \frac{(m_b ZY - m_c ZX)}{(m_b + m_c)} \times \\
& \bar{u}(p_1) \frac{p_\alpha}{p \cdot q} (1 - \gamma_5) v(p_2),
\end{aligned} \tag{14}$$

and the total matrix element in 2HDM becomes:

$$\begin{aligned}
M_2^{2HDM}(B_c \rightarrow \tau \bar{\nu}_\tau \gamma) = & ie \frac{G_F}{\sqrt{2}} V_{cb} f_{B_c} \varepsilon_\alpha \frac{m_\tau m_{B_c}^2}{M_H^2} \frac{(m_b ZY - m_c ZX)}{(m_b + m_c)} \times \\
& \bar{u}(p_1) \left\{ \frac{\gamma_\alpha \not{q} + 2p_{1\alpha}}{2p_1 \cdot q} - \frac{p_\alpha}{p \cdot q} \right\} (1 - \gamma_5) v(p_2).
\end{aligned} \tag{15}$$

At this accuracy it is easy to check that the modified total amplitude for the radiative leptonic B-decays of $B_c \rightarrow \tau \bar{\nu}_\tau \gamma$ is gauge invariant:

$$M_{(total)}(B_c \rightarrow \tau \bar{\nu}_\tau \gamma) = M_1^{new} + M_2, \tag{16}$$

where

$$M_1^{new} = ie \frac{G_F}{\sqrt{2}} V_{cb} f_{B_c} m_\tau \varepsilon_\alpha C^{2HDM} \bar{u}(p_1) \left\{ \frac{\gamma_\alpha \not{q} + 2p_{1\alpha}}{2p_1 \cdot q} - \frac{p_\alpha}{p \cdot q} \right\} (1 - \gamma_5) v(p_2). \tag{17}$$

Therefore, in this model the charged Higgs contribution modifies only the so-called M_1 part of the SM, and it does not induce any new contribution to the so-called M_2 (see Eq.3):

$$C^{2HDM} = \left\{ \frac{m_{B_c}^2}{M_H^2} \frac{(m_b ZY - m_c ZX)}{(m_b + m_c)} + 1 \right\}. \quad (18)$$

The 2HDM is sensitive to two basic free parameters, namely $\tan\beta$, and the charged Higgs mass M_H . If we formally set $Z \rightarrow 0$ in Eq. (18), the resulting expression is expected to coincide with the $B_c \rightarrow \tau \bar{\nu}_\tau \gamma$ decay, which was investigated in the framework of SM [6].

After lengthy, but straightforward calculation for the squared matrix element, we get:

$$|M_{total}|^2 = |M_1^{new}|^2 + 2 \operatorname{Re} [M_1^{new} M_2^\dagger] + |M_2|^2, \quad (19)$$

where

$$\begin{aligned} |M_1^{new}|^2 &= \frac{G^2}{2} |V_{cb}|^2 e^2 (-4f_{B_c}^2 m_\tau^2) |C^{2HDM}|^2 \frac{1}{(p_1 q)^2 (pq)^2} \\ &\times \left\{ 2p^2 (p_1 p_2) (p_1 q)^2 + (pq)^2 [(p_1 p_2)(2m_\tau^2 - p_1 q) + (p_2 q)(m_\tau^2 - 2p_1 q)] \right. \\ &\left. + (pq)(p_1 q) [(pp_2)(p_1 q) - (pp_1)(4p_1 p_2 + p_2 q)] \right\}, \end{aligned} \quad (20)$$

$$\begin{aligned} 2 \operatorname{Re} [M_1^{new} M_2^\dagger] &= \frac{G^2}{2} |V_{cb}|^2 e^2 (-16f_{B_c}^2 m_\tau^2) C^{2HDM} \frac{1}{(p_1 q)(pq)} \\ &\times \left\{ \frac{f_2(p^2)}{m_{B_c}^2} p^2 (p_1 q)(p_2 q) + (pq)^2 \left[\frac{f_2(p^2)}{m_{B_c}^2} (p_1 p_2 + p_2 q) - \frac{f_1(p^2)}{m_{B_c}^2} (p_2 q) \right] \right. \\ &\left. - \frac{f_2(p^2)}{m_{B_c}^2} [(pp_2)(p_1 q) + (pp_1)(p_2 q)] \right\}, \end{aligned} \quad (21)$$

$$\begin{aligned} |M_2|^2 &= \frac{G^2}{2} |V_{cb}|^2 e^2 16 \left[\frac{|f_1(p^2)|^2}{m_{B_c}^4} + \frac{|f_2(p^2)|^2}{m_{B_c}^4} \right] \\ &\times \left\{ (pp_2)(pq)(p_1 q) + (p_2 q) [(pp_1)(pq) - p^2(p_1 q)] \right\}. \end{aligned} \quad (22)$$

All calculations have been performed in the rest frame of the B_c meson. The dot products of the four-vectors are defined if the photon and neutrino (or electron) energies are specified.

The Dalitz boundary for the photon energy E_γ and neutrino energy E_2 are defined as follows:

$$\frac{m_{B_c}^2 - 2m_{B_c}E_\gamma - m_\tau^2}{2m_{B_c}} \leq E_2 \leq \frac{m_{B_c}^2 - 2m_{B_c}E_\gamma - m_\tau^2}{2(m_{B_c} - 2E_\gamma)},$$

$$0 \leq E_\gamma \leq \frac{m_{B_c}^2 - m_\tau^2}{2m_{B_c}}. \quad (23)$$

It is now straightforward to work out the expression for the differential decay rate in the lepton and photon energies:

$$\frac{d\Gamma}{dE_2 dE_\gamma} = \frac{1}{64\pi^3 m_{B_c}} |M_{total}|^2. \quad (24)$$

The differential ($d\Gamma/dE_\gamma$) and total decay width are singular at the lower limit of the photon energy, and this singularity which is present only in the $|M_1^{new}|^2$ contribution is due to the soft photon emission from charged lepton line. On the other hand, $|M_2|^2$ and $\text{Re}[M_1^{new}M_2^\dagger]$ terms are free from this singularity. In this limit the $B_c \rightarrow \tau\bar{\nu}_\tau\gamma$ decay can not be distinguished from the $B_c \rightarrow \tau\bar{\nu}_\tau$ decay. Therefore, in order to obtain a finite result for the decay width, we must consider both decays together. The infrared singularity arising in the $|M_1^{new}|^2$ contribution must be canceled with $O(\alpha)$ virtual correction to the $B_c \rightarrow \tau\bar{\nu}_\tau$ decay. In the SM this cancellation explicitly was shown in [13].

In this work, the $B_c \rightarrow \tau\bar{\nu}_\tau\gamma$ process is not considered as a $O(\alpha)$ correction to the $B_c \rightarrow \tau\bar{\nu}_\tau$ decay, but rather a separate decay channel with hard photon radiation. Therefore we impose a cut off value on the photon energy, which will set an experimental limit on the minimum detectable photon energy. We consider the case for which the photon energy threshold is larger than 50, MeV i.e., $E_\gamma \geq a m_{B_c}$, where $a \geq 0.01$. An integration over all the possible values of the lepton energy E_2 gives the total decay width as a function of the photon energy:

$$\Gamma = \frac{G^2 \alpha m_{B_c}^3}{64\pi^2} |V_{cb}|^2 \left\{ 4f_{B_c}^2 |C^{2HDM}|^2 \int_\delta^{1-r} dx \frac{r}{x(1-x)} \left[-4 + 8r - 4r^2 + 10x - 14rx \right. \right.$$

$$\begin{aligned}
& + 4r^2x - 9x^2 + 7rx^2 + 3x^3 + (1-x)(2-2r^2-3x+rx+2x^2)\ell n\left(\frac{1-x}{r}\right) \Big] \\
& - 4f_{B_c} C^{2HDM} \int_{\delta}^{1-r} dx \frac{rx}{1-x} \left[(1-r-x)(f_1(x)x + f_2(x)(1+r-2x)) \right. \\
& - (1-x)(f_1(x)x + f_2(x)(2r-x))\ell n\left(\frac{1-x}{r}\right) \Big] \\
& + \frac{1}{3} \int_{\delta}^{1-r} dx \left[|f_1(x)|^2 + |f_2(x)|^2 \right] \frac{1}{(1-x)^2} x^3 (2+r-2x)(1-r-x)^2 \Big\}, \tag{25}
\end{aligned}$$

where $x = 2E_{\gamma}/m_{B_c}$ is the dimensionless photon energy, $r = m_{\tau}^2/m_{B_c}^2$ and $\delta = 2a$.

3 NUMERICAL ANALYSIS

To calculate the decay width, explicit forms of the form factors f_1 and f_2 are needed. These form factors were calculated in the framework of the light-front quark model in [14], and in the light-cone QCD sum rules [3], where in [3] it was found that, the best agreement is achieved by the following pole forms for the form factors:

$$f_1(p^2) = \frac{f_1(0)}{1 - p^2/m_1^2}, \quad f_2(p^2) = \frac{f_2(0)}{1 - p^2/m_2^2}, \tag{26}$$

where

$$\begin{aligned}
f_1(0) &= 0.44 \pm 0.04 \text{ GeV}, & m_1^2 &= 43.1 \text{ GeV}^2, \\
f_2(0) &= 0.21 \pm 0.02 \text{ GeV}, & m_2^2 &= 48.0 \text{ GeV}^2.
\end{aligned}$$

On the other hand, in evaluating the decay width, we have used the following set of parameters: $G_F = 1.17 \cdot 10^{-5} \text{ GeV}^{-2}$, $\alpha = 1/137$, $m_b = 4.8 \text{ GeV}$, $m_c = 1.4 \text{ GeV}$, $m_{B_c} = 6.3 \text{ GeV}$, $m_{\tau} = 1.78 \text{ GeV}$, $f_{B_c} = 0.36 \text{ GeV}$ [15], $V_{cb} = 0.04$ [16] and, $\tau(B_c) = 0.46 \times 10^{-12} \text{ s}$ [1].

In this regard we should also recall that the free parameters of the 2HDM model namely $\tan\beta$, and M_H are not arbitrary, but there are some semiquantitative restrictions on them using the existing experimental data. The most direct bound on the charged Higgs boson mass comes from top quark decays, which yield the bound $M_H > 147 \text{ GeV}$ for large $\tan\beta$ [17]. For pure type-II 2HDM's one finds $M_H > 300 \text{ GeV}$, coming from the virtual Higgs boson contributions to $b \rightarrow s\gamma$ [18]. Furthermore, there are no experimental upper bounds on the mass of the charged Higgs boson, but one generally expects to have $M_H < 1 \text{ TeV}$

in order that perturbation theory remain valid [19]. For large $\tan\beta$ the most stringent constraints on $\tan\beta$ and M_H are actually on their ratio, $\tan\beta/M_H$. The current limits come from the measured branching ratio for the inclusive decay $B \rightarrow X\tau\bar{\nu}$, giving $\tan\beta/M_H < 0.46 \text{ GeV}^{-1}$ [20], and from the upper limit on the branching ratio for $B \rightarrow \tau\bar{\nu}$, giving $\tan\beta/M_H < 0.38 \text{ GeV}^{-1}$ [21].

For illustrative purposes we consider four values of $\tan\beta$, namely $\tan\beta = 5, 10, 30$ and 50 and let $m_{H^\pm} = 150 \text{ GeV}$. Then we consider two values of m_{H^\pm} , namely $M_{H^\pm} = 200, 400 \text{ GeV}$, and we allow $\tan\beta$ to range between 0 to 60 . The results of this numerical analysis are graphically shown in figures 2-4. In these figures the differences between the 2HDM's and the SM are shown for two different fixed cut off values, i.e., $\delta = 0.016$ and $\delta = 0.032$ both for Model I and Model II.

The results for the differential decay branching ratio $\text{dBR}(B_c \rightarrow \tau\bar{\nu}\gamma)/dx$ as a function of $x = 2E_\gamma/m_{B_c}$ for different values of $\tan\beta$, $M_H = 150 \text{ GeV}$ are presented in Fig.2, while the branching ratio (BR) for $B \rightarrow \tau\bar{\nu}\gamma$ decay is shown in figure 3-4 as a function of M_H for various values of $\tan\beta$, and as a function of $\tan\beta$ for different values of M_H . Results are shown for Model I, and Mode II.

It is observed that Model II gives both a bigger differential decay branching ratio, and a bigger branching ratio than the SM rates of (up to three orders of magnitude [$M_H = 150 \text{ GeV}$]) for large values of $\tan\beta > 20$, while for small values of $\tan\beta < 10$ results approaches its SM value.

In model I the situation is somewhat totally different. Curves overlap with the SM results all the way. This behavior obviously reflects the H^\pm fermion couplings, which are proportional to $\cot\beta$ in this model.

In conclusion, this study shows that the branching ratios for $B_c \rightarrow \tau\bar{\nu}\gamma$ could be at the level of 10^{-4} in the 2HDM, which may be detectable at the ongoing LHC. When enough B_c events are collected, this decay will be able to provide alternative channel to extract new restrictions for the free parameters $\tan\beta$ and M_{H^\pm} of the 2HDM model.

Figure Captions

Figure 1. : The relevant Feynman diagrams, responsible for $B_c \rightarrow \tau \bar{\nu} \gamma$ decay.

Figure 2. : The dependence of the differential Branching ratio of $d\text{BR}(B_c \rightarrow \tau \bar{\nu} \gamma)/dx$ as a function of the photon energy $x = 2E_\gamma/m_{B_c}$ for both models Model I, and Model II.

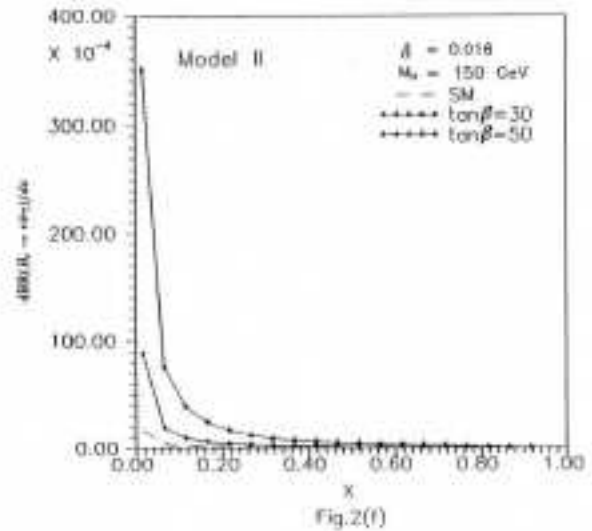
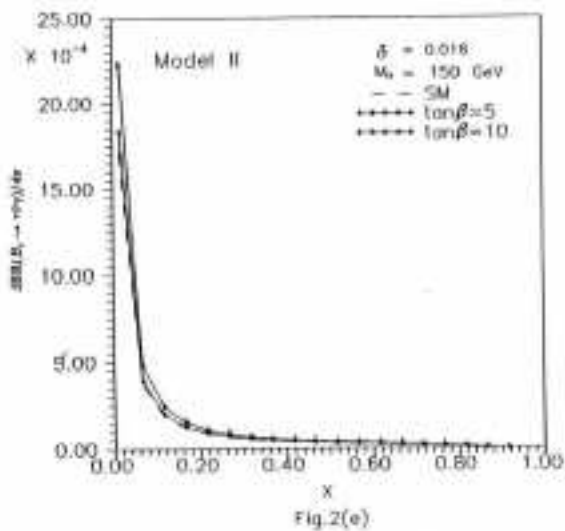
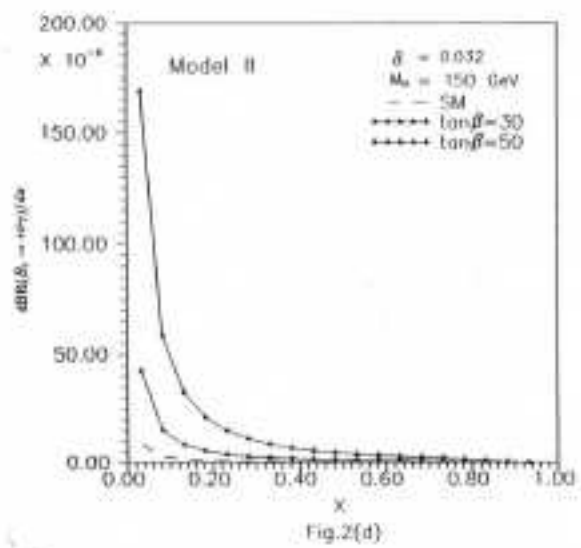
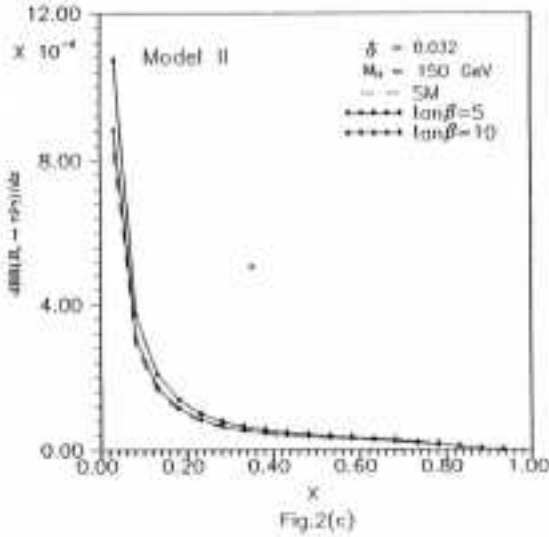
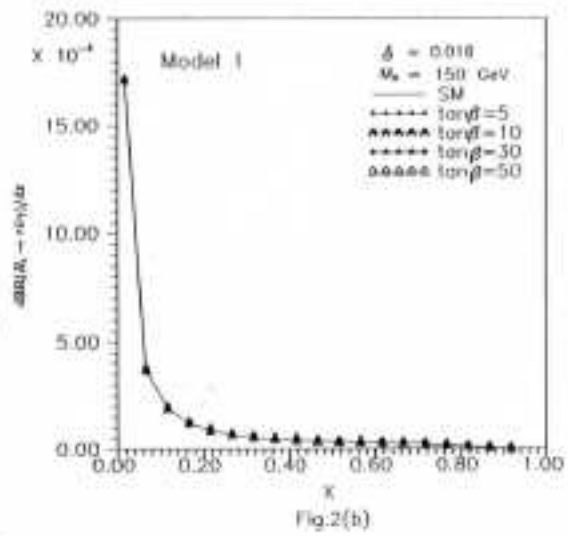
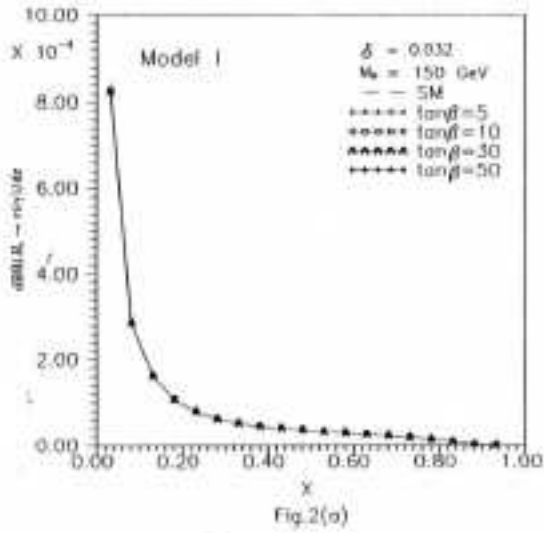
Figure 3. : The dependence of the Branching ratio on the charged Higgs boson mass at different values of $\tan\beta$ for both models Model I, and Model II.

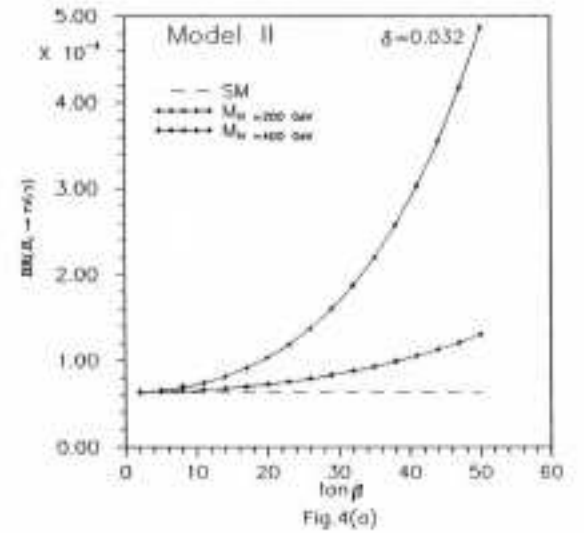
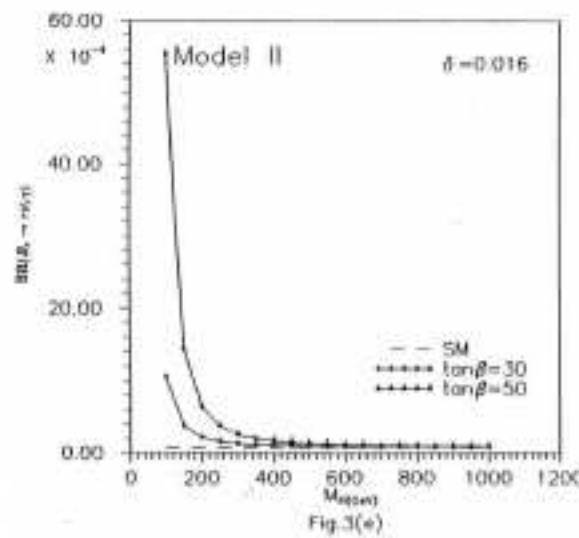
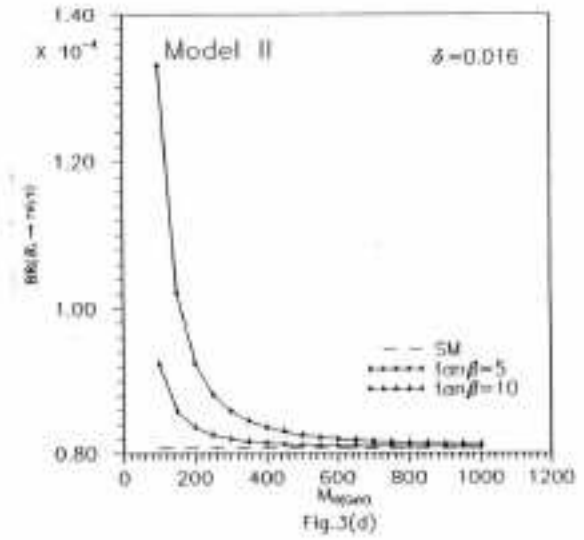
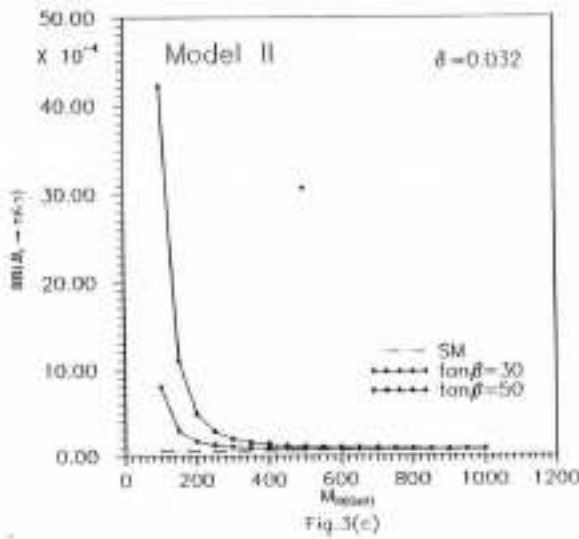
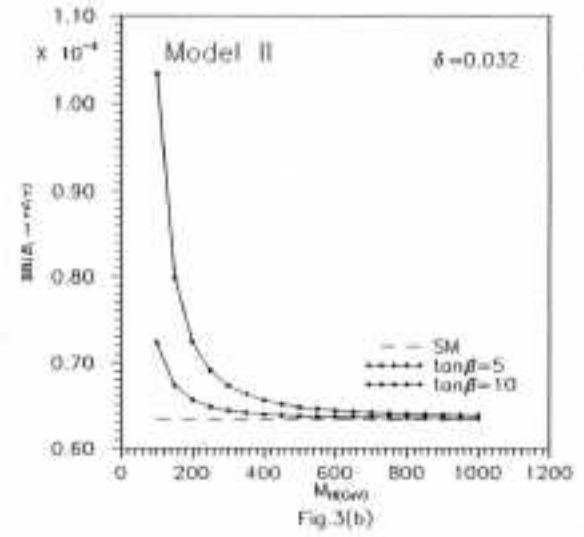
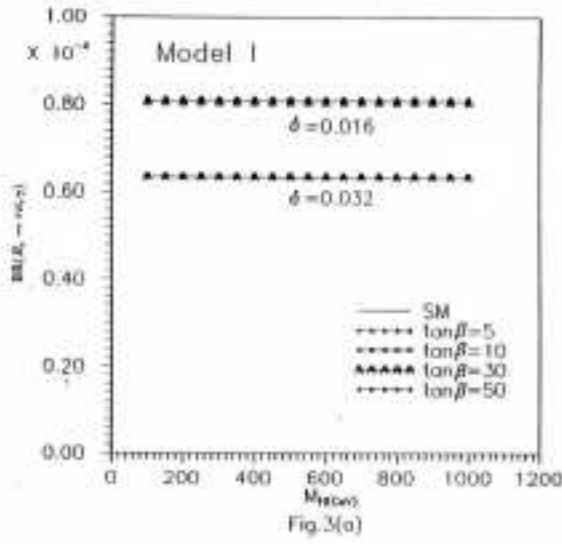
Figure 4. : The dependence of the Branching ratio on $\tan\beta$ at different values of the charged Higgs boson mass for both models Model I, and Model II.

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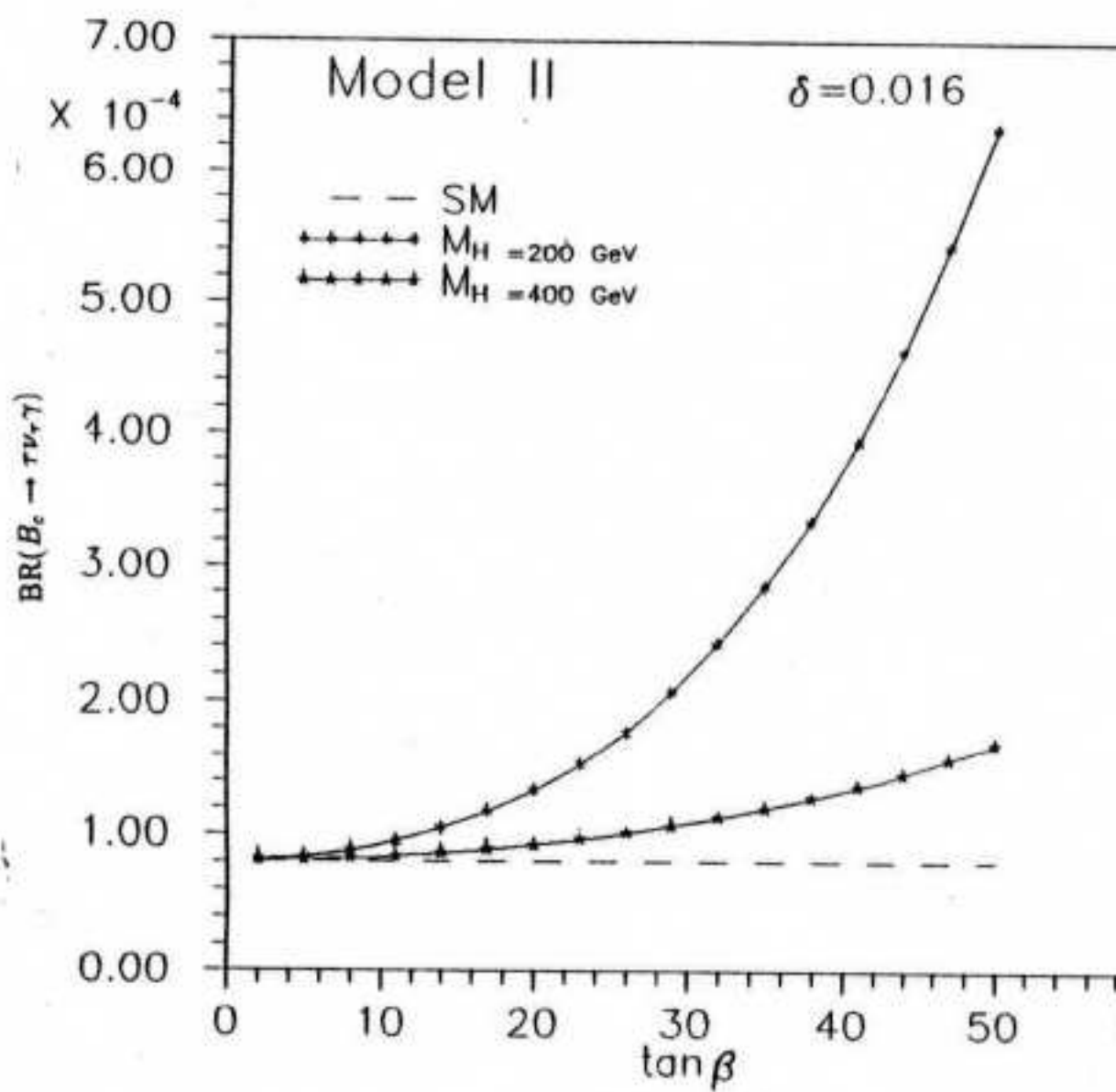


Fig.4(b)